ENTROPY MAN

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Preface

The seeds for this book were sown in the 1970s, four decades ago, when I was then working as group economist for the engineering corporation Babcock International Plc. At that time the group employed about 30,000 people in subsidiaries spread all around the world, engaged in the design, manufacture and installation of capital plant for a variety of industries, including nuclear & conventional power generation, coal mining, gas, chemicals & petroleum, steel, automotive, cement, construction and environmental engineering. Prior to that, my formal university education had included a degree in engineering at University of Bath and a Masters in management science, allied to student sandwich experience with Amalgamated Power Engineering *[now a subsidiary of Rolls Royce]* and ASEA Brown Boveri, Switzerland, followed by working for SKF, the Swedish bearing manufacturer, often considered to be a bell-weather of world economic output.

From the 1980s onwards I worked as director of a consultancy, and subsequently also as an expert witness to the Courts, which roles I continue to the present day. These experiences have taught me to maintain an enquiring, dispassionate and impartial mind regarding the complex workings of human endeavour, the natural world and changes arising thereof.

My particular research interests in those early years concerned the parallels between the disciplines of economics and thermodynamics *[the science of energy & heat]* and how they relate to each other, as a result of which I published two peer-reviewed papers on the subject in *Energy Economics [1979 & 1982]*. Subsequent to these I gave presentations to international gatherings of government ministers, energy industry executives and academia.

Not being based at a university however, and with no research grant at my disposal, my main thrust had been to make a living from consultancy and therefore, until more recently, opportunities to spend time on research were few. Nevertheless, by the turn of the millennium I was able to find time to return to some research and published another peer-reviewed paper in the *International Journal of Exergy [2007]*, followed up by several working papers on monetary aspects and energy models. Subsequently in 2009 I wrote a technical book on the subject, to bring together all the facets of the work into a coherent whole: *'Thermoeconomics – a thermodynamic approach to economics'*. The book was subsequently revised, corrected and added to, up to a third edition *[2012]*, covering topics such as production and consumption processes, employment, money, interest rates and bonds, energy resources, climate change and sustainability, and including more up to date statistics. It has now been superseded by this book.

Whilst not being tied to a university, government agency, industrial enterprise or other organisation has disadvantages in terms of recognition and time available for research, it does nevertheless have the advantages of freedom to investigate and pursue a course of enquiry of one's own choosing and of drawing conclusions independent of those that pay the piper or who may have pre-set agendas, however well-intentioned these may be.

The nature of the subject requires significant proof for economists and scientists to accept that similarities between thermodynamic and economic phenomena might imply more than just a passing analogy or isomorphism, and relations between the two disciplines have rarely been comfortable, with scientists sometimes having scant regard for the work of economists; and many economists believing that science has little to offer their discipline which, by its nature, can be thought of as anthropocentric rather than eco-centric. One eminent energy scientist advised me that he did not know of an economist who could follow a thermodynamic argument. Certainly a concept such as entropy means very little to most economists, still less to the man in the street – money is their language of communication. The latter is not, however, the language that Nature and the environment converse in.

This book is intended for a mixed readership of scientists, economists and those of an enquiring mind. It is a challenge therefore to convey the nub of the argument in terms that all can appreciate, with particular reference to the effects of potential problems such as 'peak resources', humankind's effect on the ecosystem and the maelstrom that would ensue should resource failure or climate change ever come about to a significant degree.

While some chapters, notably chapters 4 through to 8, do contain some mathematical expressions, explanatory points are included to guide non-mathematicians onwards. Formal proofs and derivations have been relegated to the notes on each chapter.

Although economic man may currently have the ascendency, he does not actually *'own'* the Earth. He is there on sufferance, and the Earth would quickly forget him along the ecological timescale, should human civilisation fail or spoil the proceedings.

I am indebted to my wife Alison for all her support and for providing me with an atmosphere conducive to my research.

John Bryant

CHAPTER 4 ECONOMIC STOCKS AND FLOWS

To connect further the world of economics to that of thermodynamics, we turn first to the analysis of gas systems. In the physical world, the pressure of a gas can be raised by compressing its volume, or by absorbing energy from a heat source with a higher temperature level. Likewise, it is generally accepted in economics that the price of a unit of volume output can go up and down according to supply and demand. This was one of the similarities that economist Paul Samuelson noted in his Nobel lecture.

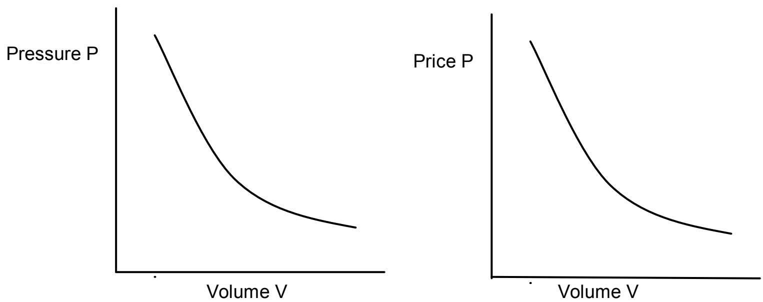


Figure 4.1 P-V Diagrams.

Of course, we can all think of lots of things that look similar, but that does not mean that they are related. The moon is round, as is the Sun, and from the Earth they look about the same size, but one would not equate the two.

For a start, 'volume' here means two different things. In science it means a collection of gas molecules in a space, the molecules being either corralled inside a non-flowing enclosure, as in a balloon, or flowing over time, as along a pipe. In economics it generally means a flow of product per unit of time into or out of a stock. Then again, it might be argued that while even a small volume of a gas contains a very large number of molecules, homogenous and at first glance fairly evenly but chaotically dispersed *[Loschmidt's number indicates 2.6 x 10^{19} per cm^3 at 0°C and a pressure of 1Atm]*, some economic systems can be composed of just a few items, and unevenly dispersed, though others can have large numbers of items, particularly if one looks at market or country levels of aggregation.

To examine the characteristics of gases in more detail, recourse is made to the kinetic theory of an ideal gas, which many of us are taught about in school physics lessons. The theory teaches us that for a closed ideal gas system made up of a number **N** of molecules, which are perfectly elastic and are busy moving about colliding and exchanging kinetic energy with each other, all within an enclosure of volume **V**, then this effects a pressure **P** on the walls of the enclosure. If, through the application of heat from outside, the gas molecules are made to vibrate and move about faster, they then increase their rate of exchange of kinetic energy and the gas accumulates internal energy resulting in a rise in temperature **T,** with pressure and/or volume potentially increasing too; rather like a sealed balloon being heated. A similar effect is obtained if the volume of a balloon is compressed by an outside force. The relationship between the factors is given by the ideal gas equation:

$$PV = NkT$$

Where **k** is the Boltzmann Constant, which we met in chapter 1. It is a fixed measure of the average kinetic energy of a molecule of a gas per degree of temperature *[Kelvin scale, not Fahrenheit or Centigrade]*, and therefore temperature **T** constitutes a measure of the relative kinetic energy level of the gas; the higher it is, the higher the velocities of the gas molecules and the shorter the time between collisions of the gas molecules within the walls of the enclosure. Thus the total energy level of the gas molecules is equal to **N** multiplied by **k** multiplied by **T**. Scientists utilise the concept of temperature by constructing a *scale* with reference to observable characteristics of physical things, such as the freezing and boiling points of water, the expansion and contraction of fluids and solids, and other phenomena. It provides a base to measure and venture further.

Distinctions are made between flow and non-flow systems. For a non-flow system, such as a balloon or a closed piston/cylinder mechanism, generally the number of gas units **N** is held constant, with pressure **P** and volume **V** being a function of temperature **T**. For a flow system, such as a gas moving through a pipe or turbine, **N** becomes a flow of molecules per period of time, with a corresponding flow of gas volume **V** per unit of time; though varying with pressure **P** and temperature **T**.

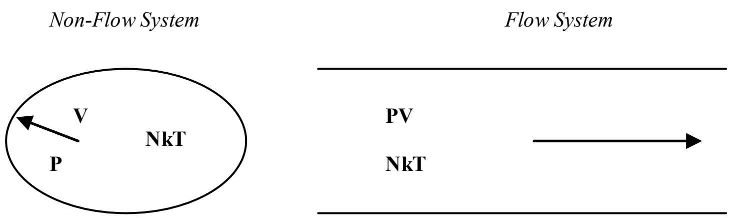


Figure 4.2 Flow and Non-flow Thermodynamic Systems.

Turning now to an economic system, imagine a stock, controlled by a human, having a number **N** of units of a particular good or carrier of value, with a defined specification, where each unit is assumed to have a constant amount of productive content **k,** *not* dependent on price or volume. A volume of goods/carriers **V** per unit of time flows in and out of the stock. The stock can be of any size relative to the flow, from large to small *[as in instantaneous]*. The relationship of the system with the outside world is that the particular carriers of value can be exchanged by the human for units of a different good or carrier of value controlled by another human. The exchange takes place over a period of time at an agreed price and according to an *Index [or a degree of a scale] of Trading Value* **T** with which each stock is *'turned over'* during that period.

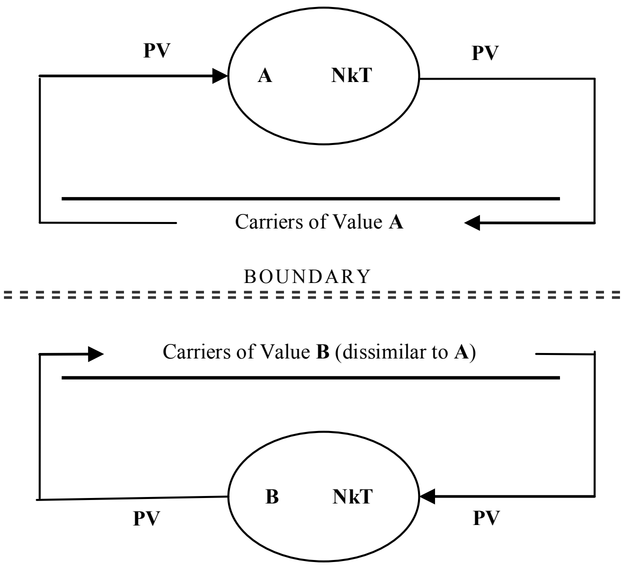


Figure 4.3 A Simple Economic Exchange System.

If the carriers in one of the stocks could increase their index of trading value **T** over the period, then the volume flow rate in an out of their stock could go up *and/or* the unit value of exchange of goods *[the price]* could also change over the period. Thus the relationship of the variables in each stock is given by an ideal economic equation:

$$PV = NkT$$

With respect to the constant **k**, it should be emphasised, as stated in chapter 3, that we are not ascribing a price or utility value, but a productive content; that is, a *physical* value that a unit of economic stock possesses. A bolt still looks like a bolt, and a barrel of oil still looks like a barrel of oil. Utility, however, is a concept invented by economists to explain the paradox of say diamonds having much higher and potentially variable *prices* attached to them, through an exchange or trade, than can be explained in terms of the cost of their production or their usefulness, compared to say water. As already stated, economics gets around the notion of productive content **k** by assuming that everything can conveniently be given a value of **k** equal to 1, being one car of a very specific design, colour and age, a diamond of a specific cut, hue, weight, rarity and history of ownership, one £, one shoe of a specific design, colour and age, a litre of water of a defined quality – in fact one of anything, provided that it is *exactly* defined in all its aspects. Thus the relationship for each specific economic stock flow process becomes:

$$PV = NT$$

With the number of stock units **N** being 'turned over' by index **T** to become input or output value flow **PV**.

The notion of *price* for each unit of stock in the modern economy is now fixed by relating each stock to a stock of money, with money deemed to have a productive content *equal* to its price. Thus *both* the productive content and the price of a currency are deemed to be one; $1 or £1. This is not to say that the productive content of a currency does not change – witness hyperinflation in a poorly run economy for example – but that it is deemed to be constant in order to facilitate the exchange of productive content between humans.

The relationship **PV=NT** is similar to that for the Quantity Theory of Money, familiar to economists, particularly those of a monetarist leaning. However, while the index of trading value **T** is readily equated to the velocity of circulation of a currency, there is no reason why it should not be compared also with the velocity of circulation of other items of exchange, such as the turnover rate of a producer stock. Even a labour force can be regarded as a stock, with new entrants coming from births and upbringing, through to retirement at the end of a working life. It is just that the lifetime comparisons are very different, from almost instantaneous for electronic money, to forty or fifty years for a member of the labour force; and much longer for some resources, if not noticeably depleted, and for some waste stocks, if not recycled back into the eco-system.

It is important to stress that the index of trading value **T** so described here is one based on value flow, and not just volume flow. If value flow, equal to price **P** multiplied by volume flow **V** per unit of time**,** can vary on one side of the equation, then on the other side of the equation value must be able to vary as well. Of the factors on the other side, the embodied value/productive content **k** that can be carried or held by a carrier, although inherently a value, is a *fixed nominal value* of **1** *[of anything]* and is deemed to be constant. It is the same whether trading occurs or not. As it is possible that the stock number **N** of carriers of value in a particular system configuration may also be fixed *[e.g. shares in issue]*, then the index of trading value **T** must be able to embody both changes in volume *and price* in order to make both sides of the equation compatible with one another.

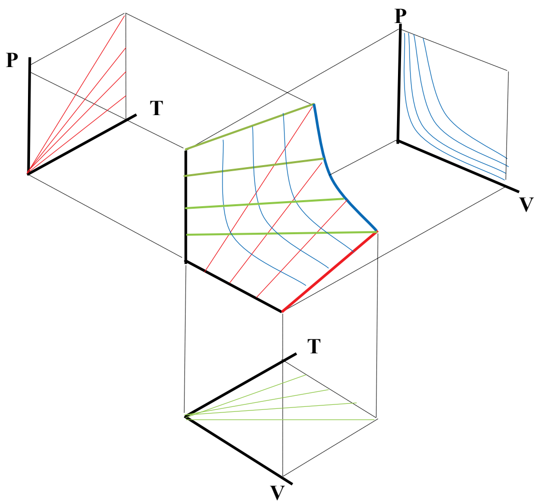


Figure 4.4 Price, volume flow and the index of trading value [for a single stock number N=1].

Two particular differences between gas and economic systems that arise from the development so far should be emphasised. First, a gas system is defined by the volume containing the gas. It acts in a spatial and 3-dimensional manner. In an economic system, however, volume flow **V** *per unit of time* does not have a 3-dimensional configuration, and the value contained by the economic unit can be said to act at a 'point'. It may be a pin, a bank note or a power station, but it is still considered to be acting at a '*point' [but having the property of flow and frequency of turnover]*. This aspect does not matter, however, as the economic flow value is likewise defined as per item 'point' flow, and not per spatial volume as in a gas system. The first difference of the two systems is illustrated by figure 4.5.

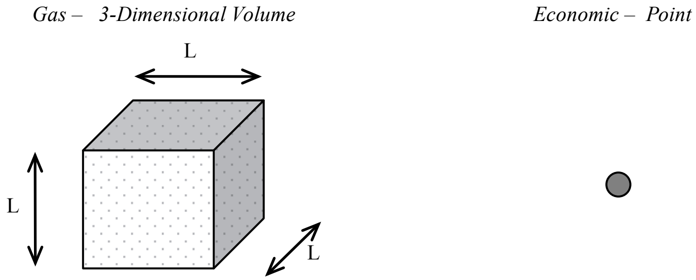


Figure 4.5 Gas & Economic Formats.

The second difference is that of throughput flow and time. In a gas *flow* system, throughput flow is defined by reference to volume flow **V** per unit of time on the left-hand side of the equation, and flow of molecules **N** per unit of time on the other side. The same time dimension occurs on both sides of the equation and is of the same measure, that is **V** and **N** proceed in tandem together. In a *non-flow* gas system, on the other hand, time does not enter into consideration on *either* side. The number **N** of molecules remains the same, and though the volume **V** can change through expansion and compression, it is not flowing in the sense of continually changing its contents per unit of time.

Economic systems, however, have elements of *both* flow and non-flow processes. Thus on the left hand side of the equation we might envisage a volume flow throughput **V**, retaining the same time relationship *[items per transaction time – a year etc]* as that of a thermodynamic flow process, such as inputs and outputs from a stock. But on the other side of the equation the stock quantity **N** is ordinarily not flowing. It can of course change in size, according to the difference between input and output flows, but otherwise it stays where it is. On the right hand side of the equation therefore, the notion of flow is transferred to the index of trading value **T**, which becomes a velocity of circulation relative to the central stock **N**, and is related to *both* the relative *volume throughput rate per unit of time* of a stock item and the *price of exchange*.

From all of the above analysis it can be seen that the formats of the ideal gas equation and the ideal economic equation outlined so far are similar with defined parallels: pressure **P** with price per unit, volume **V** with units of output/consumption per unit of time, the number of molecules of gas **N** with the number of particular carriers of value in a stock, temperature **T** with the index of trading value, and the Boltzmann constant **k** with the embodied value/productive content per unit of the particular carrier, but notionally given the value of **1**, as in information theory. In both gas and economic systems time is balanced out on both sides of the equation.

It is important to note also that while the productive content entering or leaving a particular defined stock is the *same*, that accumulating through intervening production/consumption processes *changes*, arising from creation/destruction of productive content, with *[mostly]* undefined efficiency losses occurring at each process. This aspect will be developed in a later chapter.

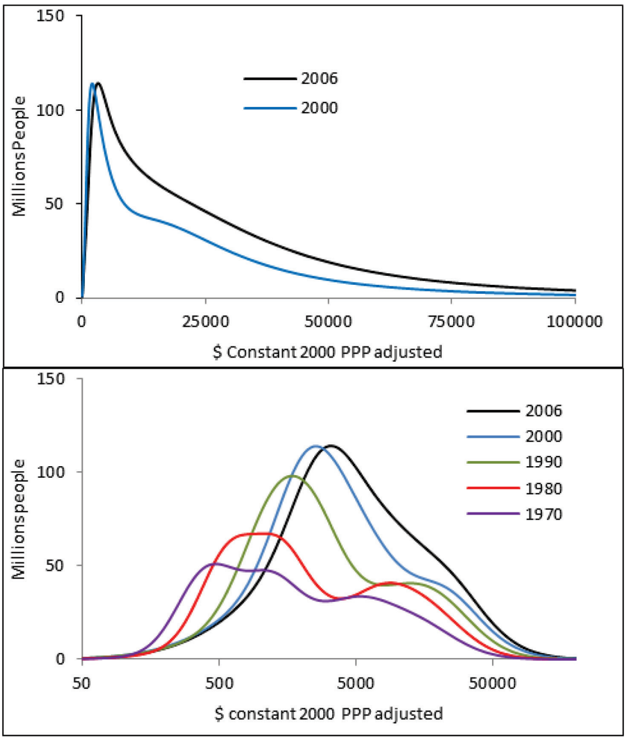
The Distribution of Income & Wealth

Returning to the impact of human labour, which has changed from historical past, when it provided essentially only 'man-power' *[with the assistance of domesticated animal power]*, in the modern economy much power is now provided by machines which consume energy. This change was discussed at chapter 3 and illustrated at figure 3.3, whereby the productive content contribution of resources is largely assumed by economists to be attributed to humankind – as measured by the gross domestic product per capita, which can be subdivided into a wage element and a profit/rent *[wealth]* element. At the aggregate national level therefore, an economist would assume a mean productive content **k** per individual of **1**, replace the index of trading value **T** by an income rate **w**, being the GDP/head per unit of time, and similarly replace the stock level **N** with the population count, to give another interpretation of the definition of trading value.

$$PV = Nw$$

Within this overall mean value there is then a distribution of individual values, according to how much each individual can command of the GDP, based on a number of criteria, such as age and development, work rate, hours put in, personal attributes and abilities from physical, cerebral to management, closeness to and control of the source of value, accepted ownership and others. One might call this a kinetic value, measuring the relative amount and speed with which value passes through an individual's hands, compared to that passing through another's.

It is well known in economics that income/wealth **w** per head is distributed about mean values, but that this distribution is of a skewed nature – a few people command rather a lot of income/wealth, and rather more people command a lot less. Figure 4.6 is illustrative of the position for the world economy, with a similar effect among most of the contributing economies to the world total, albeit at different levels, from the developed world to the fast growing economies of China, India and others. The upper chart includes a linear income scale to show the unequal distribution and the long declining tail to the higher income levels, and the lower chart includes a logarithmic income scale to enable the full range of incomes to be displayed. It will be noted from the upper chart that as mean income rises, the distribution broadens and shifts to the right. The lower chart shows how the world economy has developed since 1970. During this time world population increased from 3.6m in 1970 to 6.5m in 2006 and the gap between developed and developing countries appeared to be closing to a more uniform distribution.



Sources: The upper chart is constructed by the author based on distribution data from Pinkovskiy and Sala-i-Martin (2009). The lower chart reproduces figure 21 from the same research. Parametric Estimations of the World Distribution of Income, NBER WP 15433

Figure 4.6 World Distribution of Annual Income 1970 – 2006 (population increasing).

Economists utilise particular distribution curves to describe this relationship, of which the log-normal distribution is the more commonly used, but others include Gamma and Maxwell-Boltzmann.

In a similar manner, it is found that individual gas particles within a volume of gas display variable *[kinetic]* energy levels, the variation being distributed in a skewed manner about a mean energy value of **kT** *[the Boltzmann constant multiplied by the temperature level]*. Scientists commonly describe this variation by the Maxwell-Boltzmann distribution, named after its originators. The similarity between gas and economic distributions has been picked up by the 'econophysics' school, which was alluded to in chapter 3.

Figure 4.7 shows the shape of a Maxwell Boltzmann frequency curve for a population of constant size, having a mean income rate of ϖ per annum. The mean income rate ϖ replaces the mean energy value of **kT** in the Maxwell Boltzmann distribution**.** As the mean income rate increases, as in growth in GDP per head for example, so the curve flattens and moves to the right with a larger proportion of persons commanding output value at a higher level. Should the population level also rise, then the flattened curve grows in size, as in the world figures illustrated at figure 4.6.

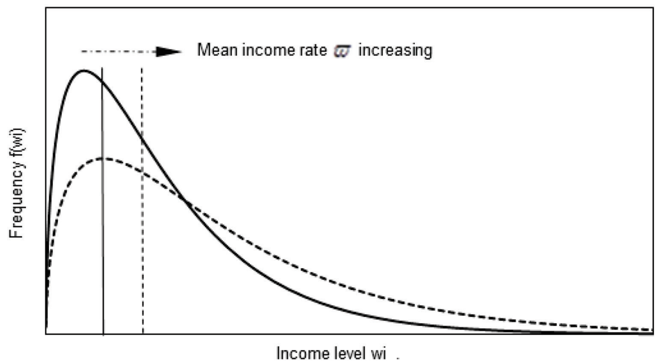


Figure 4.7 Maxwell Boltzmann income distribution (constant population).

For interested readers the equation for the curve is given in the notes to the chapter.

It is emphasised again that one should not lose sight of the origins and destinations of productive content from resources to asset accumulations and waste, as opposed to the assumed generation attributed to humans, as measured by income and GDP per head. Further, no assumption is made about the equitableness or not concerning the relative skew in an income distribution *[Piketty 2014]* for one human community compared to another, all that is inferred is that skew of some kind is natural, as is the case in gas systems.

Elasticity

A particular aspect of the relationship between pressure and volume in a thermodynamic gas system is that pressure is not always inversely proportional to volume, but is related through an index **n** of expansion or compression, as in the following equation:

$$PV^{n} = C \quad \textit{[where C is a constant]}$$

This is usually described as a *polytropic* relationship, meaning that it can be adapted to fit any situation.

A similar polytropic relationship occurs also in the world of economics, with price **P** being not necessarily just inversely proportional to volume demand **V**, and where the index **n** is referred to as an elastic index. The demand for some economic goods may be highly elastic with regard to a change in price level, while for others, a change in price does not impact much on demand. The economic concept of elasticity explains this difference well. Figure 4.8 shows a range of economic curves, which has a parallel with the thermodynamic analogy, with price replacing pressure.

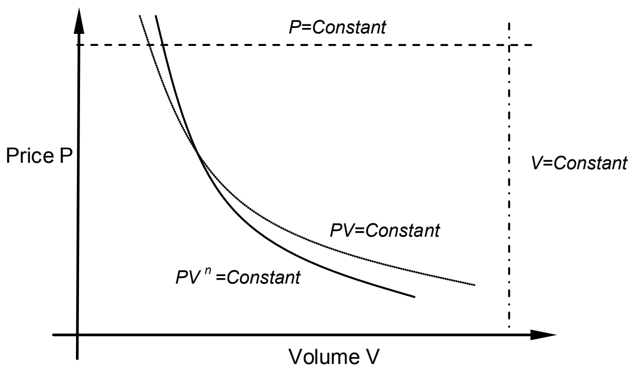


Figure 4.8 Price – Volume relationships.

Readers of an algebraic bent will note that all of the relationships can be obtained just by changing the elastic index **n**. For instance, when **n** = 0, we have a constant price situation, and when **n** = ∞ *[infinity]*, we have a constant volume position. Further, by using the relationship of price and volume flow to our index of trading value **PV=NT**, it is also possible to derive elastic relationships to cover the index of trading value **T** as well. For instance for a single unit of stock *[N=1]* the polytropic equation $PV^n = C$ can also be expressed as:

$$T = CV^{(1-n)} \quad \textit{[where C is a constant]}$$

With volume throughput flow **V** for a single unit of stock expressed in terms of the index of trading value **T** instead of price **P**. Thus a whole family of economic relationships can be established, from which to derive a thermodynamic structure relating to any product or resource proceeding through a stock–flow system.

The First Law of Thermodynamics

The First Law of Thermodynamics is really all about the conservation of energy. Energy cannot be created or destroyed, but it can be changed from one form to another. By way of example figure 4.9 illustrates the principle for a moveable piston inside a cylinder open at one end. A gas is held in the space inside. There are three kinds of energy involved. A mechanical force can be applied to or received from the piston, effecting a movement of the piston and some work done **G**, some heat **Q** can be transferred across the cylinder wall, and the 'internal' energy **U** of the gas can go up or down *[measured as a rise or fall in its temperature **T**]*. All that the First Law of Thermodynamics states is that changes in these three energy forms must balance each other out.

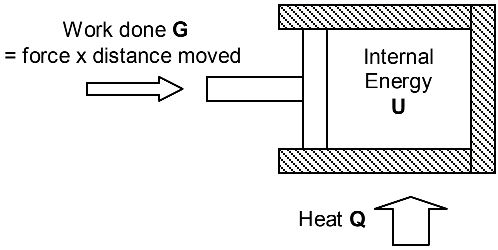


Figure 4.9 Illustration of the First Law for a Thermodynamic System.

The First Law for a non-flow thermodynamic gas system is therefore expressed as:

Heat supplied = work done + change in internal energy

Or, for the mathematically inclined, in differential terms:

$$dQ = dG + dU$$

For example, if a force is applied to move the piston inwards, the gas is compressed, reducing the volume inside the cylinder and raising the pressure**.** The temperature of the gas may go up, with the molecules moving around faster, accumulating some internal energy. Some heat may pass across the cylinder wall. Similarly, if some heat from outside is applied to the cylinder, the temperature of the gas inside rises, accumulating some internal energy. The increased internal energy of the gas results in an increased pressure on the cylinder wall and the piston head, and some work is done to move the piston outwards, increasing the volume so as to equalise the pressure inside with the pressure outside.

It is but a step to conceive that a similar sort of process occurs in economics, but concerning 'value' instead of 'energy'. We cannot say that value and energy are the same, clearly they are different in concept, but the underlying principles applying to each of them are strikingly similar.

Imagine a stock of a particular economic good, each unit of which has a fixed productive content of **k** = 1, as shown in figure 4.10. The stock is fed at one end by input work value flow **G** per unit of time of the same good *[being a function of price **P** multiplied by volume flow **V** per unit of time, price being compared to a comparator called money]*, with a similar output work value flow of the good coming out the other end of the stock.

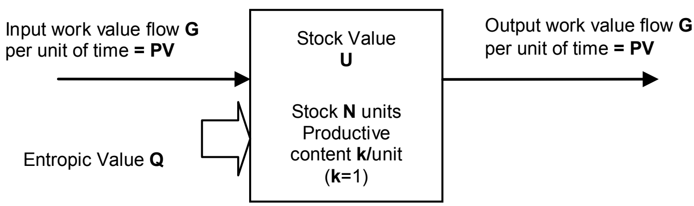


Figure 4.10 An Economic Stock.

One can picture three main events that can impact on the stock. First, additional or reduced flow of *Work Value* **G** per unit of time can occur, being defined as a *change in volume flow* **V** of the particular good multiplied by its price **P**. Thus the volume flow rate per unit of time, entering and subsequently leaving the stock, rises or falls. Mathematically, in differential terms we can write this as:

$$dG = PdV$$

Change in work value flow rate = price x change in work volume flow rate

The second event that can occur is a change in the value **Q** that can be put into or taken out of the system. Examples of value **Q** include a scarcity or abundance of the particular good engendered by a change in consumer demand compared to the available supply, a change in consumers' utility preferences, new money coming into the system, or the consumption of the productive content of another good, some of the value of which can then be *added* or *transferred* to the particular good via a production process to impact on the work value flow **G** feeding into the stock. Value **Q** therefore does *not* represent the initial volume throughput of the particular good. We'll call this the *Entropic Value* added or taken out.

The third event that can occur is a change in the economic value **U** of the stock, which we will call the *'Internal Value'*. There is a difference between the internal value **U** and the stock productive content **Nk**. The latter is set by reference to the number of units **N** in the stock and the *non-variable* productive content **k** of each unit *[equated to 1 for an exactly defined type of product]*. The internal value **U**, on the other hand, is a *variable* value by reference to the index of trading value **T** relating to goods entering and leaving the stock per unit of time. It will also be a function of the relative lifetime spent in the stock compared to the flow and time base of economic activity. We'll call this proportion the *value capacity or lifetime coefficient* **ω.** Some stocks, such as commercial and industrial ones, on average have high *natural* volume throughput rates compared to their size *[$\omega \ll 1$]* and others have low volume throughput rates *[$\omega \gg 1$]*. Money gets turned over several times a year; bonds, capital and human stock tend to last many years, some seasonal items a year. As an alternative, the inverse of the *value capacity or lifetime coefficient* **ω** could be regarded as a *rate of return* **r**, being the *natural* proportion that leaves or joins a stock, per unit time base of economic activity. Thus, for example, the natural rate of return **r** for a stock having 10 items, of which one joins and leaves in a year, would be

10%, and the lifetime coefficient **ω** would be equal to 10. We can therefore set out the change in the stock internal value in differential terms as:

$$dU = N\omega dT$$

Change in the stock internal value = the number of units in the stock x the value capacity (or lifetime) coefficient x the change in the index of trading value.

The thermodynamic analogy to the value capacity coefficient **ω** is the *specific heat capacity*, being the amount of energy that has to be incorporated in a fixed mass of an element in order to raise its temperature by one degree ºK *[Kelvin temperature scale]*. The value varies with the elements in the periodic table. The following table shows values obtained by scientific experiment for some typical gases:

	$Jg^{-1}K^{-1}$ *
Hydrogen	14.30
Helium	5.19
Steam (water)	2.01
Air (Nitrogen & Oxygen)	1.02
Argon	0.52
Xenon	0.16
Radon	0.09

* *Scale: Joules per gram per degree Kelvin*

Source: Chemix School - Periodic Table

Table 4.1 Specific Heat Capacities for selected gases.

It can be seen that the *specific heat capacity* to raise temperature by a fixed amount varies significantly by element. A lot of energy has to be inputted to a mass of hydrogen, but very little to Radon. The scale does not have a time element, unlike an economic process.

The economic concept of change in internal value is one that can incorporate changes in both volume flow of productive content and entropic value added or taken away. The following example is illustrative of the process.

Imagine a trader with a stock of a *particular* item of fashion clothes, each of which has a fixed productive content of **k** = 1, defined exactly by the material it was made of, its style, logo and other relevant attributes. The trader is in the business of buying and selling such stock. In a normal year he trades with a work value flow **G** equal to the price **P** he charges multiplied by the volume flow **V** he normally achieves, giving a turnover of **G = PV**, equal also to the number of units in the stock multiplied by the index of trading value: **PV = NT**. In a good year, however, when demand is brisk engendering an introduction of entropic value **Q**, he may be able to increase his volume sales or charge higher prices for his stock, increasing his work value flow **G**. The internal value **U** of the stock is therefore perceived to go up, in tandem with the stock index of trading value **T**, even though the particular items of clothing have not changed in shape or form. If, half way through his trading year, demand suddenly collapses with entropic value **Q** being pulled out, the trader may be forced to sell his stock at much lower prices, and not make so many sales, reducing his work value flow **G**. The perceived internal value **U** of the stock therefore goes down. The internal value **U** of an economic stock is therefore a function of the index of trading value **T** and, as has been pointed out earlier in this book, the index of trading value **T**, in an economic sense, is a measure of *both* the volume speed *and* the relative value level *[the price]* at which economic stocks are being turned over.

On such a basis, an economic equivalent could be set out for the First Law of Thermodynamics:

Entropic Value introduced /taken away is equal to the change in work value flow rate, plus any change in the internal value of the stock.

$$dQ = dG + dU$$

There is nothing implicit in the First Law of Thermodynamics to say that in a thermodynamic system some proportion of heat supplied to an engine must be rejected, and therefore that the cycle efficiency cannot be unity. All that the First Law states is that net work cannot be produced during a cycle without an appropriate supply of heat, i.e. that a perpetual motion machine of the first kind is impossible. Likewise in our economic system, an increased flow of work output value cannot be achieved without an increased supply of value arising from input of additional resources and consumption of additional human effort and/or capital stock. Generally one cannot get something for nothing. Thus, for the First Law, there seems to be a parallel between thermodynamic and economic systems.

It is conceivable that an economic system in some sense may actually fulfil the First Law, as illustrated by the charts at figures 3.3 and 3.4, in that an economic system, being circular in nature, has equal but opposite flows of production and consumption values, equating to the idea of conservation of energy, implicit in the First Law. What may not be measured or represented fully, however, is the substantial irreversibility built in as resource value is converted to *useful* output, with associated *less-useful* value being ejected to the ecosystem, with consequential irreversibility occurring. This is the domain of the Second Law of Thermodynamics.

The Second Law of Thermodynamics

Whereas the First Law is concerned with the conservation of energy, the Second Law of Thermodynamics, by contrast, is an expression of the fact that some heat must *always* be rejected during a thermodynamic cycle. The law can be stated as:

"It is impossible to construct a system which will operate in a cycle, extract heat from a reservoir, and do an equivalent amount of work on the surroundings."

There is always some heat left over that cannot be converted into work output. In a fossil-fired power station, for example the temperature of the flue gas is still significantly higher than the ambient temperature of the atmosphere, into which it is released, entailing a loss of low grade energy to the ecosystem. Further, energy is also lost via the power lines used to distribute electricity to consumers and industry; and even before the power station, much energy is discarded, including that associated with mining, transporting and refining the fuels ready for use. Thus, all along the way, losses occur which cannot be recouped. At the final consumption stage, the 'high order' electrical energy that is so useful to humankind is then consumed to provide heat and to drive the machines and apparatus associated with the 'modern' age. At each stage therefore, bits of heat energy **Q** and work value **G** are passed along and some heat energy **Q** is discarded.

Scientists measure the *relative* bits of heat energy **Q** acquired or discarded by reference to the temperature **T** at which these occurred. The relative measure, or property, is called entropy, and is designated by the symbol **S**. Mathematically it is expressed in differential terms as:

$$dS \geq \frac{dQ}{T}$$

With an inequality sign inserted to indicate that entropy change is greater than or equal to the relative heat change taking place with respect to the temperature level. Only in the case of a completely reversible change, however *[literally one going back exactly to the starting point without a difference in energy change, compared to the forward path]*, can the two sides become equal.

In thermodynamics entropy is a property that measures the amount of energy in a physical system that cannot be used to do work. In statistical mechanics it is defined as a measure of the probability that a system would be in such a state, which is usually referred to as the "disorder" present in a system, which concept we have already come across earlier in this book. Thus to repeat the Second Law: it is impossible to construct a system which will operate in a cycle, extract heat from a reservoir and do an equivalent amount of work on the surroundings. Entropy tends to rise; it is a measure of dispersed value. In general irreversibility is the order of the day.

Similarly, in economic terms, the Second Law could be re-phrased as:

"It is impossible to construct an economic system which will operate in a cycle, extract productive content from a resource reservoir and do an equivalent amount of work, in terms of manufacture of productive content."

There is always a bit of productive content left over that cannot be incorporated into product output and which is therefore discarded. Economic systems are not efficient, and involve a significant level of irreversibility. One cannot unwind the production of economic output back to its constituent inputs without expending even more effort. Imagine for example trying to 'undo' a pizza to extract the exact amounts of flour, cheese, tomatoes and heat from which it was made, and to recover the exact value and human effort that was put in to make it. While a degree of reversibility is obtained by the regeneration of the human species, capital stock and agricultural renewal and by the recycling of scrap from production and consumption back into the production process, the process of acquiring such *'order'* is more than offset by the increased *'disorder'* discarded to the ecosystem.

However, the problem with the structure of an economic system is that it appears to defy the Second Law of Thermodynamics. This apparent non-sequitur arises because no subtraction in the financial accounts is made for the efficiency losses and loss of productive content, arising from production, that nature picks up and returns to the ecosystem. Everything is calculated on the basis of a *money valuation* being placed on the final output of each product and service that is exchanged between humans, *inclusive* of all the losses incurred along the way. The calculation is not based on the net productive content. Consumers pay money for all the electricity they buy, irrespective of the discarded energy productive content that goes up the chimney or is deposited as ash heaps. At this point economic man appears to ignore half of the story and assumes that nature takes up the slack, as depicted in figures 3.3 and 3.4 of chapter 3.

To be fair, however, *after* reaching the point of final output, much of consumption value is then effectively written off *[having been consumed]*, creating a large entropy gain, though some of this is actually retained by humans to extend their lifetime *[food, nutrient energy and well-being]* and improve their value *[education and acquired assets]*. Likewise, national accounts and accounts of corporations do include formal write-off amounts for fixed asset values, in the form of scrappage or depreciation *[creating an entropy gain]*, to give economists and investors some idea as to their net worth at periodic times. Outside of formal accounting analyses, consumers can consult agents concerning assets values of items with long lifetimes, such as automobiles, houses and other durable goods, as to their estimated residual value over time, and the amounts that they have effectively lost to Nature over time. However, the relevant value is their replacement cost, which includes all the efficiency losses of productive content that are required to be generated in order to make a replacement. No monetary payments are received from 'mother Nature' for the wastes and assets write-offs that she receives on behalf of humankind.

The reader may conclude from all of the above that formal economic analyses at the aggregate level up to the point of final output, just before consumption, largely exclude estimates of discarded waste and the associated entropy gain arising from this, and therefore that a notion of reversibility is assumed in economic accounting to this point. On this basis the inequality sign in our entropy equation would then be replaced by an 'equals' sign, with a suffix to indicate a reversible process*, though clearly this is not the case from a scientific point of view*:

$$dS = \frac{dQ}{T}_{rev}$$

Proceeding on this basis therefore, by combining the above equation with those of the economic equivalent for the First Law set out earlier, we could derive a relationship for economic entropy change in terms of changes in volume flow, price and our index of trading value. To avoid clogging the narrative with too much mathematics, however, set out as follows is an end transformation of this process, in terms of the rate of change of volume flow for a polytropic system ***[PV^n=C]*** having a single unit of stock, useful to see in the context of the economic concept of utility which will be reviewed in the next section. For interested readers, nevertheless, the formal proof of the relationship is set out in full in the notes to this chapter.

$$dS = (\omega - \omega n + 1)\frac{dV}{V}_{rev}$$

The transformation says that incremental change in entropy generation per unit of time for an economic stock having only one unit *[stock number N=1]* can be equated to the rate of growth/decline of volume throughput per unit of time, but modified by the factor in the brackets, being a function of the stock *lifetime* or *value capacity coefficient* **ω** *[the ratio of the time units of value normally take to pass through a stock compared to the trading time – years per year, seconds per second]* and the elastic index **n**. When integrated, entropy generation per unit of time is equated to a function of the logarithm of volume flow per unit of time *[plus a constant of integration C]*.

$$S = (\omega - \omega n + 1)\ln V + C$$

The transformation looks similar in construction to the logarithmic entropy formula inscribed on Boltzmann's tomb, which we saw in chapter 1. And recalling that the lifetime coefficient ***ω*** is the inverse of the natural rate of return **r**, the equation can also be written in the form:

$$S = \left(1 + \frac{1-n}{r}\right)\ln V + C$$

Figures 4.10 and 4.11 illustrate the general shape of the curve and the factor **(ω–ωn+1)**, which we will call the Marginal Entropic Index.

Readers may note from both the equation for entropy and the lower chart at figure 4.11, that when the marginal entropic index **(ω–ωn+1)** is equal to zero, then change in entropy generation becomes zero – a property which becomes significant when we consider how economic systems strive for equilibrium.

It should be cautioned, however, that in cases where volume flow rate **V** does not change, a change in entropy can still occur, but will be expressed instead as a function of either price **P** or the index of trading value **T**.

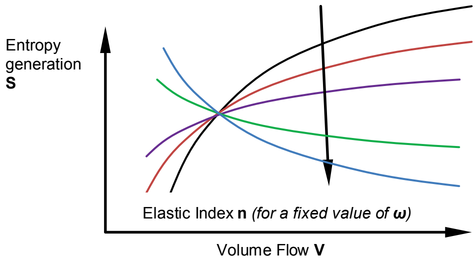


Figure 4.10 Entropy Curves for a Polytropic Process.

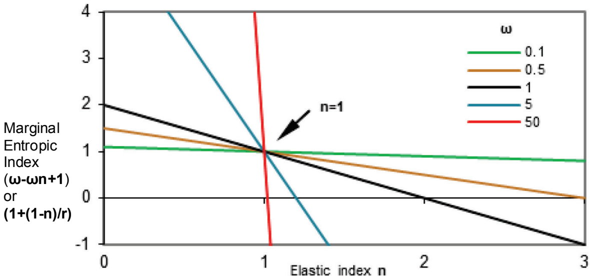


Figure 4.11 Marginal Entropic Index.

We will leave the empirical application of all of this to later chapters, but it is worth considering for a moment how entropy is to be measured in terms of economic units. In thermodynamics it is generally measured as energy per gram per degree of a scale of temperature *[Joules/g°K]*. In computers the *'bit'* is the commonly used term when dealing with binary systems. In information theory, where logarithms to the base **e** are used, the *'nat'* is considered to be the appropriate unit, which also normalizes Boltzmann's constant **k** to 1.

Readers will note from the previous analysis that economic entropy generated per unit of time is also derived to be logarithmic in nature, with incremental entropy change **dS** being effectively equated to factors multiplied by per cent changes in the volume flow rate, the index of trading value or price, and with the constant **k** also being normalised to **1**. Thus there is a similarity with information theory. However, while the *'nat'* might be considered to be the natural unit of measurement for economic entropy, it does not altogether convey the economic meaning, and we might coin the word *'cent'* in this regard.

Utility

The economic concept of utility was first thought of by Jeremy Bentham *[1748-1832]*. He imagined that the utility value of a pleasure or a pain to a human would depend on its intensity, duration, relative certainty and proximity; further, that individual degrees or amounts of utility value could be added up to measure the total social good. Other notable economists followed, contributing to the debate, including Jevons *[1835-1882]*, Marshall *[1842-1924]*, Edgeworth *[1845-1926]* and Pareto *[1848-1923]*. A number of concepts subsequently developed, such as:

- Total utility and marginal utility, the former representing the total pleasure or pain, and the latter representing the pleasure or pain from an additional amount.
- Cardinal utility and ordinal utility, the former attaching numbers to utility, and the latter abandoning this idea and just placing different utilities in 'order' of choice.
- Experienced utility and decision utility, the former representing that 'felt' by a consumer, and the latter reflecting the choices made by consumers through their 'revealed preferences'.

In simple terms, utility theory posits that consumers can choose between *consuming* more or less of a variety of goods, according to their circumstances and preferences. Each consumer is said subconsciously to attach a utility value to each good, and their total utility **Y** is then couched in terms of a consumption set of volumes of all the goods each consumer wishes to purchase and consume over a time period *[a good purchased for the long term would spread over more than one time period]*, such that the total purchased value is less than or equal to the total budget or wage available to each consumer for that time.

A basic tenet of utility theory is that as each consumer demands more and more of a particular good, their utility with respect to that good rises, but grows slower and slower as their potential level of satisfaction causes them progressively to turn to other possibilities on which to spend their income.

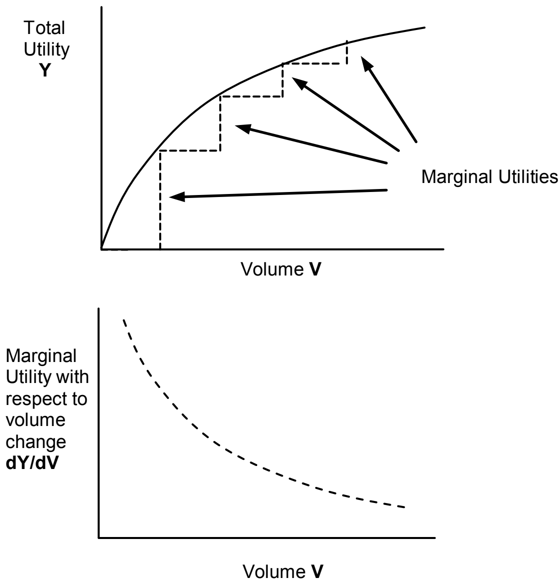


Figure 4.12 Utility as a function of Volume.

Thus their marginal utility with respect to volume for the particular good falls with an increasing volume consumption rate. This aspect is enshrined in the Law of Diminishing Marginal Utility, which states that at consumer equilibrium the marginal utility of one good with respect to a change in volume demanded, divided by its price **P,** is equal to the marginal utility of another good with respect to a change in volume demanded, divided by its price, each of these being equal to a common marginal utility per \$ or £ of income. The relationship is set out in terms of *partial* utility derivatives with respect to volume *(∂Y/∂V)* for each good **a**, **b**….**n**, reflecting the separate contributions of each good to the total utility of the consumer:

$$\frac{\left(\partial Y/\partial V\right)_a}{P_a} = \frac{\left(\partial Y/\partial V\right)_b}{P_b} = \ldots = \frac{\left(\partial Y/\partial V\right)_n}{P_n}$$

The Law of Diminishing Marginal Utility constitutes a basic input to the law of downward sloping demand curves – price being inversely a function of volume, as per the curves in figures 4.1 and 4.8 earlier in this chapter. A number of utility functions are in common use in economics to explain particular preferences, of which the familiar logarithmic curve is one of the more widely used.

A scientist will readily appreciate that no direct reference is made to the underlying productive content of each good *[given a nominal value of 1 in this book]*, only the price to be paid and the *partial* marginal utility values with respect to volume attached to each good by a particular consumer. These are both variables, and the latter value, according to economic theory, depends upon the view of each consumer and supply and demand only. It is also a fact of life, however, that *'consumer equilibrium'* is rarely if ever reached and maintained, with factors continually impacting on the situation over time to affect the status quo.

It is worth taking a little time out for a moment to think about how life forms, other than humans, assess instinctively the *'utility value'* of particular forms of productive content appropriate to their way of life, for humans are not alone in this assessment. A pride of lions might have feelings of hunger and desperation if they have not fed for some time, but once a prey is caught and killed, their marginal utility to eat declines progressively as their hunger is gradually sated by having consumed more and more of the prey. Once their hunger is fully sated they will likely not seek to catch another prey for some time. Wild animals and birds will fight, with a threat of pain or death, to defend the *'utility'* to them of their sources of food and survival, with each having a *feeling* or *instinct*, through feedback mechanisms of senses, regarding the threats and opportunities to their way of life.

Of course, it goes without saying that there is a great deal of difference between the demand for entirely unessential consumer goods that now occurs at one end of the scale in some so-called advanced human societies *[consumerism taken to the* n^{th} *degree]* down to the fight for everyday survival that occurs at the other end of the living world. But the principle is the same.

A scientist might say that a good that is the object of our consumer or wild animal has a high level of 'order' of productive content about it that makes it useful, with a relatively low starting entropy level. But as the good is consumed over time, some of the productive content is abstracted as use value to the consumer and the rest is discarded as low order waste with a corresponding net rise in entropy over time. Food and energy are obvious examples here, but the modern 'throwaway' society, whereby many goods land up in waste systems much before the end of their theoretical useful life, is another. It would not be surprising therefore to find a link between utility and entropy, even if at first they seem far removed from each other. Indeed, several researchers have considered this to be a possibility, as indicated in chapter 3.

In economics, recognition of utility occurs at the interface of two stock systems, that of a consumer wishing to procure a good, and a supplier with goods to offer. A third stock is mostly also involved, that of money linking the two such that barter is avoided. A positive marginal utility value regarding a good therefore exists with the consumer immediately before the point of purchase, is confirmed on purchase *[the revealed preference]* and thereafter the utility of the good *[to the consumer]* begins to decline as consumption takes place.

A consumer, having bought a good to improve his *'state of order'* might feel that he had just acquired some *negentropy*, such that his entropy level at that point had just declined. However he will have exchanged other goods or money for the good he had just bought, and these would have left his stock, to be picked up and used by others. Unless he had scooped a bargain, his state of order therefore would not likely have changed by a huge margin; though of course by enough to persuade him to make the purchase. Once the good was in the consumer's hands, however, entropy would gradually have been created as the good went through a process of consumption over time. Even so, if the consumer had not bought the product, it is likely that entropy would have been created via the consumption of the goods or money he would otherwise not have exchanged for the single good, though not necessarily by the same amount.

Thus, in summary, utility resides with the human purchaser or 'owner' at the start of ownership, and entropy creation resides with the *purchased* or *'product'* over time. Utility might therefore be defined as *potential economic entropy* to be generated over time on consumption.

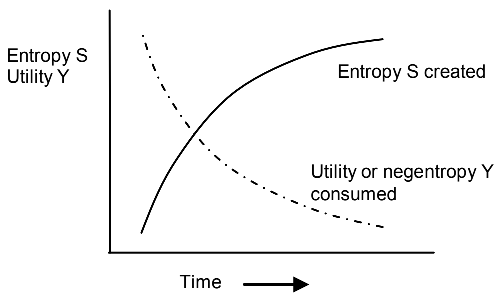


Figure 4.13 Single product consumption over time, entropy and utility changes.

As a first requirement, any thermodynamic process considered must be able to provide the impetus to allow price and utility to vary quite independently of the underlying productive content. From the First Law of Thermodynamics, the work done **G** alone will not provide such an impetus, since it is concerned *only* with changes in volume flow of productive content. The most likely candidate therefore is the entropic value **Q** added or taken away, since that constitutes essentially new money, abundance and scarcity and changes in demand, all of which can influence consumers' purchasing preferences.

Looking at a single consumer's product stock therefore, we could imagine such a stock containing only one unit *[N=1]*. Further we could apply this assumption to the formula for the marginal entropy change for a single unit of stock for the general polytropic case stated earlier in this chapter, which can fit any form of price-volume relationship, to compute an individual consumer's marginal entropy for that product:

$$dS = (\omega - \omega n + 1)\frac{dV}{V}_{rev}$$

And for this single consumer, we could also relate his/her wage or budget **w** to the total value flow of the good **PV** he/she can purchase:
:

$$PV = w$$

Proceeding even further, we could imagine that the consumer only had one unit of wage/budget to spend per unit of time, and therefore that his/her wage/budget availability **w** was equal to £1 or $1. Thus:

$PV = 1$, or inverting: $V = 1/P$

Last, we imagine that the consumer could only spend his/her unit of budget/wage on the one product. Thence, by substitution into the marginal entropy change formula and transposing the terms, we can write:

$$\left(\frac{dS/dV}{P}\right) = (\omega - \omega n + 1)$$

Thus, for a single type of good, marginal entropy with respect to volume, divided by price, is equated to a function of the elastic index, unitised to a budget/wage rate of one *[one $ or £]*. Compare this relationship with that for the Law of Diminishing Marginal Utility and readers cannot fail to note that the format of the left-hand side is just the same, but with entropy replacing utility, though proceeding in the opposite direction *[see figure 4.13]*. Readers may note also that the relationship becomes even further simplified if a product has an elastic index of **n=1**, with price **P** being inversely proportional to volume **V**, in that the right-hand side of the equation is then equated to **1**, irrespective of what stock *lifetime coefficient* **ω** a product may have, as shown in figure 4.11 earlier. Figure 4.14 illustrates the relationship of entropy and marginal entropy to consumption volume flow, in line with standard economic presentations of marginal utility.

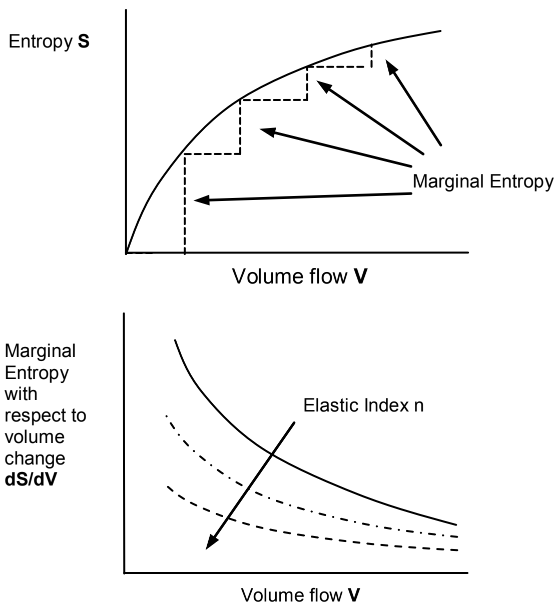


Figure 4.14 Entropy as a function of consumption volume flow.

Finally, there is nothing to prevent the range of goods being expanded to cover all those among the consumer's choice. Thence a straight derivative (*dS/dV*) can be replaced by a series of partial derivatives *(∂S/∂V)*. The conclusion must be that utility is likely to be related to entropy, though proceeding in the opposite direction - negentropy.

Continuing further, a scientist will say that entropy is additive, that is, all the bits of entropy created can be added together. Summating this across many products and many consumers one could hypothesise that, as with utility, bits *[or 'cents' as coined in this book]* of entropy could be added together to measure the social good.

It should be recognised that while each consumer may seek to maximise his utility over time from the goods that he buys, and thereby maximise the potential economic entropy to be generated upon their consumption over time, and subject also to the variable availability and mix of factors which will ensure his survival and those of his offspring, this is a continuing, non-equilibrium process and not an absolute one, and therefore that equilibrium is never held at the maximum point, but is continually changing, as the factors around it, such as suppliers and other consumers, likewise change, influencing consumers' budgets, production and the mix of goods thereof. A thermodynamic representation of economic processes is by definition non-equilibrium in nature. Figure 4.14 illustrates the principle:

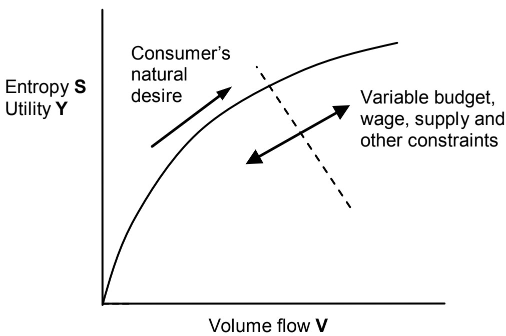


Figure 4.15 Consumer Utility/Entropy Maximisation.

While economists commonly represent a consumer's budget or wage as the constraint, with spending rising up to or below that constraint, the presentation here is that a multiple of relevant factors can influence their decisions; consumers can overspend as well as underspend, demand can exceed supply and vice-versa. The scientist's representation of this effect is the Le Châtelier Principle, which we met in chapter 1.

"If a change occurs in one of the factors under which a system is equilibrium, then the system will tend to adjust itself so as to annul as far as possible the effects of that change".